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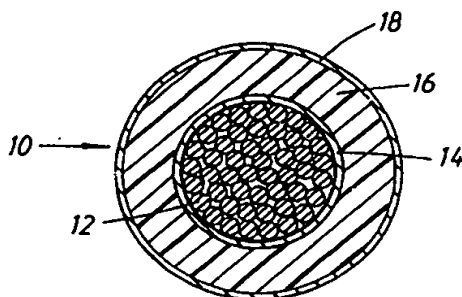
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<b>(21) International Application Number:</b> PCT/SE97/00903 <b>(22) International Filing Date:</b> 27 May 1997 (27.05.97)  <b>(30) Priority Data:</b> 9602079-7                      29 May 1996 (29.05.96)                      SE 9602091-2                      29 May 1996 (29.05.96)                      SE  <b>(71) Applicant (for all designated States except US):</b> ASEA BROWN BOVERI AB [SE/SE]; S-721 83 Västerås (SE).  <b>(72) Inventors; and</b> <b>(75) Inventors/Applicants (for US only):</b> LEIJON, Mats [SE/SE]; Hyvlargatan 5, S-723 35 Västerås (SE). MING, Li [CN/SE]; Högbyskogsväg 1, S-723 41 Västerås (SE). KYLANDER, Gunnar [SE/SE]; Stentorpsgratan 16 A, S-723 43 Västerås (SE). CARTENSEN, Peter [SE/SE]; Sjövägen 62, S-141 42 Huddinge (SE). RYDHOLM, Bengt [SE/SE]; Brunnbygatan 68, S-722 23 Västerås (SE). ANDERSSON, Per [SE/SE]; Malmgatan 11, S-703 54 Örebro (SE). TEMPLIN, Peter [SE/SE]; Dybecksgatan 4 B, S-731 40 Köping (SE).  <b>(74) Agent:</b> ASKERBERG, Fredrik; L.A. GROTH & CO. KB, P.O. Box 6107, S-102 32 Stockholm (SE).		<b>(81) Designated States:</b> AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, CZ (Utility model), DE, DE (Utility model), DK, DK (Utility model), EE, ES, FI, FI (Utility model), GB, GE, GH, HU, IL, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, TJ, TM, TR, TT, UA, UG, US, UZ, VN, YU, ARIPO patent (GH, KE, LS, MW, SD, SZ, UG), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG).  <b>Published</b> With international search report.

(54) Title: INSULATED CONDUCTOR FOR HIGH-VOLTAGE WINDINGS



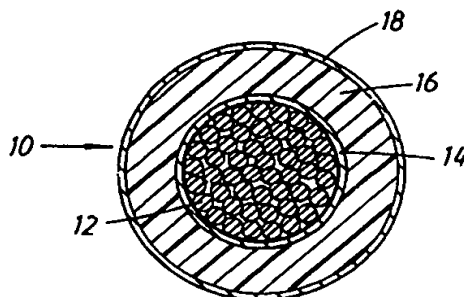
## (57) Abstract

The invention relates to an insulated conductor (10) for high-voltage windings in electric machines. The insulated conductor (10) comprises one or more strands (12), an inner, first conductive layer (14) surrounding the strands (12), a first insulating layer (16) surrounding the inner, first conductive layer (14) and an outer, second conductive layer (18) surrounding the first insulating layer (16). The second conductive layer (18) has a resistivity which on the one hand minimizes the electric losses in the second conductive layer (18), and on the other hand contributes to the voltage induced in the second conductive layer (18) minimizing the risk of glow discharges.



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**(54) Title:** INSULATED CONDUCTOR FOR HIGH-VOLTAGE WINDINGS**(57) Abstract**

The invention relates to an insulated conductor (10) for high-voltage windings in electric machines. The insulated conductor (10) comprises one or more strands (12), an inner, first conductive layer (14) surrounding the strands (12), a first insulating layer (16) surrounding the inner, first conductive layer (14) and an outer, second conductive layer (18) surrounding the first insulating layer (16). The second conductive layer (18) has a resistivity which on the one hand minimizes the electric losses in the second conductive layer (18), and on the other hand contributes to the voltage induced in the second conductive layer (18) minimizing the risk of glow discharges.

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## INSULATED CONDUCTOR FOR HIGH-VOLTAGE WINDINGS

## TECHNICAL FIELD:

The present invention relates in a first aspect to an insulated conductor for high-voltage windings in electric machines.

A second aspect of the present invention relates to a rotating electric machine or static electrical machine comprising an insulated conductor of the type described above.

10

The invention is applicable in rotating electric machines such as synchronous machines or asynchronous machines as well as static electrical machines as power transformers and power reactors. The invention is also applicable in other electric machines such as dual-fed machines, and applications in asynchronous static current cascades, outer pole machines and synchronous flow machines, provided their windings consist of insulated electric conductors of the type described in the introduction, and preferably at high voltages. "High voltages" here refer to electric voltages exceeding 10 kV. A typical working range for an insulated conductor for high-voltage windings according to the invention may be 1-800 kV.

20

## BACKGROUND ART:

In order to be able to explain and describe the machine, a brief description of a rotating electric machine will first be given, exemplified on the basis of a synchronous machine. The first part of the description substantially relates to the magnetic circuit of such a machine and how it is constructed according to classical technique. Since the magnetic circuit referred to in most cases is located in the stator, the magnetic circuit below will normally be described as a stator with a laminated core, the winding of which will be referred to as a stator winding, and the slots in the laminated core for the winding will be referred to as stator slots or simply slots.

The stator winding is located in slots in the sheet iron core, the slots normally having a rectangular or trapezoidal cross section as that of a rectangle or a trapezoid. Each winding phase comprises a number of series-connected coil groups connected in series and each coil group comprises a number of series-connected coils connected in series. The different parts of the coil are designated coil side for

the part which is placed in the stator and end winding end for that part which is located outside the stator. A coil comprises one or more conductors brought together in height and/or width.

- 5 Between each conductor there is a thin insulation, for example epoxy/glass fibre.

The coil is insulated from the slot with a coil insulation, that is, an insulation intended to withstand the rated voltage of the machine to earth. As insulating material, various plastic, varnish and glass fibre materials may be used. Usually,  
10 so-called mica tape is used, which is a mixture of mica and hard plastic, especially produced to provide resistance to partial discharges, which can rapidly break down the insulation. The insulation is applied to the coil by winding the mica tape around the coil in several layers. The insulation is impregnated, and then the coil side is painted with a graphite-based paint to improve the contact with the  
15 surrounding stator which is connected to earth potential.

The conductor area of the windings is determined by the current intensity in question and by the cooling method used. The conductor and the coil are usually formed with a rectangular shape to maximize the amount of conductor material in  
20 the slot. A typical coil is formed of so-called Roebel bars, in which certain of the bars may be made hollow for a coolant. A Roebel bar comprises a plurality of rectangular, parallel-connected copper conductors connected in parallel, which are transposed 360 degrees along the slot. Ringland bars with transpositions of 540 degrees and other transpositions also occur. The transposition is made to avoid the  
25 occurrence of circulating currents which are generated in a cross section of the conductor material, as viewed from the magnetic field.

For mechanical and electrical reasons, a machine cannot be made in just any size. The machine power is determined substantially by three factors:

- 30 - The conductor area of the windings. At normal operating temperature, copper, for example, has a maximum value of 3-3.5 A/mm<sup>2</sup>.  
- The maximum flux density (magnetic flux) in the stator and rotor material.  
- The maximum electric field strength in the insulating material, the so-called dielectric strength.

35

Polyphase ac windings are designed either as single-layer or two-layer windings. In the case of single-layer windings, there is only one coil side per slot, and in the

case of two-layer windings there are two coil sides per slot. Two-layer windings are usually designed as diamond windings, whereas the single-layer windings which are relevant in this connection may be designed as a diamond winding or as a concentric winding. In the case of a diamond winding, only one coil span (or possibly two coil spans) occurs, whereas flat windings are designed as concentric windings, that is, with a greatly varying coil span. By coil span is meant the distance in circular measure between two coil sides belonging to the same coil, either in relation to the relevant pole pitch or in the number of intermediate slot pitches. Usually, different variants of chording are used, for example short-pitching pitch, to give the winding the desired properties.

The type of winding substantially describes how the coils in the slots, that is, the coil sides, are connected together outside the stator, that is, at the end windings ends.

Outside the stacked sheets of the stator, the coil is not provided with a painted conductive earth-potential layer. The end winding end is normally provided with an E-field control in the form of so-called corona protection varnish intended to convert a radial field into an axial field, which means that the insulation on the end windings ends occurs at a high potential relative to earth. This sometimes gives rise to corona in the end-winding-end region, which may be destructive. The so-called field-controlling points at the end windings ends entail problems for a rotating electric machine.

Normally, all large machines are designed with a two-layer winding and equally large coils. Each coil is placed with one side in one of the layers and the other side in the other layer. This means that all the coils cross each other in the end winding end. If more than two layers are used, these crossings render the winding work difficult and deteriorate the end winding end.

It is generally known that the connection of a synchronous machine/generator to a power network must be made via a  $\Delta$ /YD-connected so-called step-up transformer, since the voltage of the power network normally lies at a higher level than the voltage of the rotating electric machine. Together with the synchronous machine, this transformer thus constitutes integrated parts of a plant. The transformer constitutes an extra cost and also has the disadvantage the advantage that the total efficiency of the system is lowered. If it were possible to manufacture



machines for considerably higher voltages, the step-up transformer could thus be omitted.

During the last few decades, there have been increasing requirements for rotating electric machines for higher voltages than for what has previously been possible to design. The maximum voltage level which, according to the state of the art, has  
5 been possible to achieve for synchronous machines with a good yield in the coil production is around 25-30 kV.

Certain attempts to a new approach as regards the design of synchronous machines  
10 are described, inter alia, in an article entitled "Water-and-oil-cooled Turbogenerator TVM-300" in J. Elektrotechnika, No. 1, 1970, pp. 6-8, in US 4,429,244 "Stator of Generator" and in Russian patent document CCCP Patent 955369.

15 The water- and oil-cooled synchronous machine described in J. Elektrotechnika is intended for voltages up to 20 kV. The article describes a new insulation system consisting of oil/paper insulation, which makes it possible to immerse the stator completely in oil. The oil can then be used as a coolant while at the same time using it as insulation. To prevent oil in the stator from leaking out towards the  
20 rotor, a dielectric oil-separating ring is provided at the internal surface of the core. The stator winding is made from conductors with an oval hollow shape provided with oil and paper insulation. The coil sides with their insulation are secured to the slots made with rectangular cross section by means of wedges. As coolant oil is used both in the hollow conductors and in holes in the stator walls. Such cooling  
25 systems, however, entail a large number of connections of both oil and electricity at the coil ends. The thick insulation also entails an increased radius of curvature of the conductors, which in turn results in an increased size of the winding overhang.

30 The above-mentioned US patent relates to the stator part of a synchronous machine which comprises a magnetic core of laminated sheet with trapezoidal slots for the stator winding. The slots are tapered since the need for insulation of the stator winding is less towards the interior of the rotor where that part of the winding which is located nearest the neutral point is located. In addition, the stator part  
35 comprises a dielectric oil-separating cylinder nearest the inner surface of the core. This part may increase the magnetization requirement relative to a machine without this ring. The stator winding is made of oil-immersed cables with the same

diameter for each coil layer. The layers are separated from each other by means of spacers in the slots and secured by wedges. What is special for the winding is that it comprises two so-called half-windings connected in series. One of the two half-windings is located, centered, inside an insulating sleeve. The conductors of the stator winding are cooled by surrounding oil. Disadvantages with such a large quantity of oil in the system are the risk of leakage and the considerable amount of cleaning work which may result from a fault condition. Those parts of the insulating sleeve which are located outside the slots have a cylindrical part and a conical termination reinforced with current-carrying layers, the purpose of which is to control the electric field strength in the region where the cable enters the end winding.

From CCCP 955369 it is clear, in another attempt to raise the rated voltage of the synchronous machine, that the oil-cooled stator winding comprises a conventional high-voltage cable with the same dimension for all the layers. The cable is placed in stator slots formed as circular, radially located openings corresponding to the cross-section area of the cable and the necessary space for fixing and for coolant. The different radially located layers of the winding are surrounded by and fixed in insulating tubes. Insulating spacers fix the tubes in the stator slot. Because of the oil cooling, an internal dielectric ring is also needed here for sealing the oil coolant off against the internal air gap. The disadvantages of oil in the system described above also apply to this design. The design also exhibits a very narrow radial waist between the different stator slots, which implies a large slot leakage flux which significantly influences the magnetization requirement of the machine.

A report from Electric Power Research Institute, EPRI, EL-3391, from 1984 describes a review of machine concepts for achieving a higher voltage of a rotating electric machine with the purpose of being able to connect a machine to a power network without an intermediate transformer. Such a solution, judging from is judged by the investigation to provides good efficiency gains and great economic advantages. The main reason for considering it possible in 1984 to start developing generators for direct connection to power networks was that at the time a super conducting rotor had been produced. The large magnetization capacity of the super conducting field makes it possible to use an air gap winding with a sufficient insulation thickness to withstand the electrical stresses. By combining the most promising concept, according to the project, of designing a magnetic circuit with a winding, a so-called monolith cylinder armature, a concept where the winding

comprises two cylinders of conductors concentrically enclosed in three cylindrical insulating casings and the whole structure beings fixed to an iron core without teeth, it was judged that a rotating electric machine for high voltage could be directly connected to a power network. The solution meant that the main insulation  
5 had to be made sufficiently thick to cope with network-to-network and network-to-earth potentials. The insulation system which, after a review of all the technique known at the time, was judged to be necessary to manage an increase to a higher voltage was that which is normally used for power transformers and which consists of dielectric-fluid-impregnated cellulose press board. Obvious disadvantages with  
10 the proposed solution are that, in addition to requiring a super conducting rotor, it requires a very thick insulation which increases the size of the machine. The end windings ends must be insulated and cooled with oil or freons to control the large electric fields in the ends. The whole machine must be hermetically enclosed to prevent the liquid dielectric from absorbing moisture from the atmosphere.

15 When manufacturing rotating electric machines according to the state of the art, the winding is manufactured with conductors and insulation systems in several steps, whereby the winding must be preformed prior to mounting on the magnetic circuit. Impregnation for preparing the insulation system is performed after  
20 mounting of the winding on the magnetic circuit.

#### SUMMARY OF THE INVENTION:

It is an object of the invention is to be able to manufacture a rotating electric machine for high voltage without any complicated preforming of the winding and  
25 without having to impregnate the insulation system after mounting of the winding.

To increase the power of a rotating electrical machine, it is known to increase the current in the ac coils. This has been achieved by optimizing the quantity of conducting material, that is, by close-packing of rectangular conductors in the  
30 rectangular rotor slots. The aim was to handle the increase in temperature resulting from this by increasing the quantity of insulating material and using more temperature-resistant and hence more expensive insulating materials. The high temperature and field load on the insulation has also caused problems with the life of the insulation. In the relatively thick-walled insulating layers which are used for  
35 high-voltage equipment, for example impregnated layers of mica tape, partial discharges, PD, constitute a serious problem. When manufacturing these insulating layers, cavities, pores, and the like, will easily arise, in which internal corona

discharges arise when the insulation is subjected to high electric field strengths. These corona discharges gradually degrade the material and may lead to electric breakdown through the insulation.

5 The present invention is based on the realization that, to be able to increase in the power of a rotating electrical machine in a technically and economically justifiable way, this must be achieved by ensuring that the insulation is not broken down by the phenomena described above. This can be achieved according to the invention by using as insulation layers made in such a way that the risk of cavities and pores  
10 is minimal, for example extruded layers of a suitable solid insulating material, such as thermoplastic resins, cross linked thermoplastic resins, rubber such as silicone rubber, etc. In addition, it is important that the insulating layer comprises an inner layer, surrounding the conductor, with semiconducting properties and that the insulation is also provided with at least one additional outer layer, surrounding the  
15 insulation, with semiconducting properties. By semiconducting properties is meant in this context is a material which has a considerably lower conductivity than an electric conductor but which does not have such a low conductivity that it is an insulator. By using only insulating layers which may be manufactured with a minimum of defects and, in addition, providing the insulation with an inner and an  
20 outer conductive layer, it can be ensured that the thermal and electric loads are reduced. The insulating part with at least one adjoining conductive layer should have essentially the same coefficient of thermal expansion. At temperature gradients, defects caused by different temperature expansion in the insulation and the surrounding layers should not arise. The electric load on the material decreases  
25 as a consequence of the fact that the conductive layers around the insulation will constitute equipotential surfaces and that the electrical field in the insulating part will be distributed relatively evenly over the thickness of the insulation. The outer conductive layer may be connected to a chosen potential, for example earth potential. This means that, for such a cable, the outer casing of the winding in its  
30 entire length may be kept at, for example, earth potential. The outer layer may also be cut off at suitable locations along the length of the conductor and each cut-off partial length may be directly connected to a chosen potential. Around the outer conductive layer there may also be arranged other layers, casings and the like, such as a metal shield and a protective sheath.

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Further knowledge gained in connection with the present invention is that increased current load leads to problems with electric (E) field concentrations at

the corners at a cross section of a coil and that this entails large local loads on the insulation there. Likewise, the magnetic (B) field in the teeth of the stator will be concentrated at the corners. This means that magnetic saturation arises locally and that the magnetic core is not utilized in full and that the wave form of the  
5 generated voltage/current will be distorted. In addition, eddy-current losses caused by induced eddy currents in the conductors, which arise because of the geometry of the conductors in relation to the B field, will entail additional disadvantages in increasing current densities. A further improvement of the invention is achieved by making the coils and the slots in which the coils are placed essentially circular  
10 instead of rectangular. By making the cross section of the coils circular, these will be surrounded by a constant B field without concentrations where magnetic saturation may arise. Also the E field in the coil will be distributed evenly over the cross section and local loads on the insulation are considerably reduced. In addition, it is easier to place circular coils in slots in such a way that the number of  
15 coil sides per coil group may increase and an increase of the voltage may take place without the current in the conductors having to be increased. The reason for this being that the cooling of the conductors is facilitated by, on the one hand, a lower current density and hence lower temperature gradients across the insulation and, on the other hand, by the circular shape of the slots which entails a more  
20 uniform temperature distribution over a cross section. Additional improvements may also be achieved by composing the conductor from smaller parts, so-called strands. The strands may be insulated from each other and only a small number of strands may be left uninsulated and in contact with the inner conductive layer, to ensure that this is at the same potential as the conductor.

25

The advantages of using a rotating electric machine according to the invention are that the machine can be operated at overload for a considerably longer period of time than what is usual for such machines without being damaged. This is a  
consequence of the composition of the machine and the limited thermal load of the  
30 insulation. It is, for example, possible to load the machine with up to 100% overload for a period exceeding 15 minutes and up to two hours.

One embodiment according to the invention is that the magnetic circuit of the rotating electric machine comprises a winding of a threaded cable with one or  
35 more extruded insulated conductors with solid insulation with a conductive layer both at the conductor and the casing. The outer conductive layer may be connected to earth potential. To be able to cope with the problems which arise in case of

direct connection of rotating electric machines to all types of high-voltage power networks, a machine according to the invention has a number of features which distinguish it from the state of the art.

- 5 As described above, a winding for a rotating electric machine may be manufactured from a cable with one or more extruded insulated conductors with solid insulation with a conductive layer both at the conductor and at the casing.

Some typical examples of insulating materials are thermoplastics like LDPE (low  
10 density poly ethylene) HDPE (high density poly ethylene) PP (polypropylene) PB (poly butulene) PMP (poly methylpentene) or cross-linked materials like XLPE (cross linked poly ethylene) or rubber insulation like EPR (ethylene propylene rubber) or silicone rubber.

- 15 A further development of a conductor composed of strands is possible in that it is possible to insulate the strands with respect to each other in order thus to reduce the amount of eddy current losses in the conductor. One or a few strands may be left uninsulated to ensure that the conductive layer which surrounds the conductor is at the same potential as the conductor.

20

It is known that a high-voltage cable for transmission of electric energy is composed of conductors with solid extruded insulation with an inner and an outer conductive part. In the process of transmitting electric energy it was required that the insulation should be free from defects. During transmission of electric energy,  
25 the starting-point has long been that the insulation should be free from defects. When using high-voltage cables for transmission of electric energy, the aim was not to maximize the current through the cable since space is no limitation for a transmission cable.

Insulation of a conductor for a rotating electric machine may be applied in some  
30 other way than by means of extrusion, for example by spraying or the like. It is important, however, that the insulation should have no defects through the whole cross section and should possess similar thermal properties. The conductive layers may be supplied with the insulation in connection with the insulation being applied to the conductors.

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Preferably, cables with a circular cross section are used. Among other things, to obtain a better packing density, cables with a different cross section may be used.

To build up a voltage in the rotating electric machine, the cable is arranged in several consecutive turns in slots in the magnetic core. The winding can be designed as a multi-layer concentric cable winding to reduce the number of end-winding-end crossings. The cable may be made with tapered insulation to utilize  
5 the magnetic core in a better way, in which case the shape of the slots may be adapted to the tapered insulation of the winding.

A significant advantage of a rotating electrical machine according to the invention is that the E field is near zero in the end-winding-end region outside the outer  
10 conductive and that with the outer casing at earth potential, the electric field need not be controlled. This means that no field concentrations can be obtained, neither within sheets, in end-winding-end regions or in the transition between.

The present invention also relates to a method for manufacturing the magnetic  
15 circuit and, in particular, the winding. The method for manufacturing comprises placing the winding in the slots by threading a cable into the openings in the slots in the magnetic core. Since the cable is flexible, it can be bent and this permits a cable length to be located in several turns in a coil. The end windings ends will then consist of bending zones in the cables. The cable may also be joined in such a  
20 way that its properties remain constant over the cable length. This method entails considerable simplifications compared with the state of the art. The so-called Roebel bars are not flexible but must be preformed into the desired shape. Impregnation of the coils is also an exceedingly complicated and expensive technique when manufacturing rotating electric machines today.

25

This is achieved with an insulated conductor for high-voltage windings in rotating electric machines as defined in claim 1, and also with rotating electric machines comprising an insulated conductor of the type described above according to claim  
30 7. The high-voltage cable according to the present invention comprises one or more strands surrounded by a first conductive layer. This first conductive layer is in turn surrounded by a first insulating layer, which is surrounded by a second conductive layer. This second conductive layer is earthed at at least two different points along the high-voltage cable, i.e. at the inlet and outlet of the stator. The  
35 second conductive layer has a resistivity which on the one hand minimizes the electric losses in the second conductive layer, and on the other hand contributes to

the voltage induced in the second conductive layer minimizing the risk of glow discharges.

By means of the high-voltage cable according to the invention, described above, a high-voltage cable is obtained in which electric losses caused by induced voltages in the outer conductive layer can be avoided. A high-voltage cable is also obtained in which the risk of electrical discharges is minimized. Furthermore, this is obtained with a cable which is simple to manufacture.

The invention will now be explained in more detail in the following description of preferred embodiments, with reference to the accompanying drawings.

#### BRIEF DESCRIPTION OF THE DRAWINGS:

Figure 1 shows a cross section through a high-voltage cable according to the present invention;

Figure 2 shows a basic diagram explaining what affects the voltage between the conductive surface and earth; and

Figures 3 shows a diagram illustrating the potential on the conductive surface in relation to the distance between earthing points.

#### DETAILED DESCRIPTION OF EMBODIMENTS OF THE PRESENT INVENTION:

Figure 1 shows a cross-sectional view of a high-voltage cable 10 according to the present invention. The high-voltage cable 10 shown comprises an electric conductor which may consist of one or more strands 12 of copper (Cu), for instance, having circular cross section. These strands 12 are arranged in the middle of the high-voltage cable 10. Around the strands 12 is a first conductive layer 14, and around the first conductive layer 14 is a first insulating layer 16, e.g. XLPE insulation. Around the first insulating layer 16 is a second conductive layer 18.

Figure 2 shows a basic diagram explaining what affects the voltage between the conductive surface and earth. The resultant voltage,  $U_s$ , between the surface of the second conductive layer 18 and earth may be expressed as follows:



$$U_s = \sqrt{U_{\max}^2 + U_{\text{ind}}^2}$$

(1)

where  $U_{\max}$  is the result of capacitive current in the surface and where  $U_{\text{ind}}$  is  
 5 voltage induced from magnetic flux. To avoid surface discharges  $U_s$  must be  
 $< 250$  V, preferably  $U_s < 130 - 150$  V.

In principle  $U_{\text{ind}}$  creates no problems assuming earthing at both stator ends. Thus  
 $U_s \approx U_{\max}$ , where the maximum value  $U_{\max}$  at the middle of the conductor is  
 10 given by

$$U_{\max} \approx (2\pi f C_1 U_f)^2 \frac{\rho_s l^2}{A_s}$$

15

where  $f$  = frequency;  $C_1$  = transverse capacitance per length unit;  $U_f$  = phase-to-  
 ground voltage;  $\rho_s$  = the resistivity of the conductive layer 18;  $A_s$  = the cross-  
 sectional area of the conductive layer 18 and  $l$  = the length of the stator.

20 One way of preventing losses caused by induced voltages in the second conductive  
 layer 18 is to increase its resistance. Since the thickness of the layer cannot be  
 reduced for technical reasons relating to manufacture of the cable and stator, the  
 resistance can be increased by selecting a coating or a compound that has higher  
 resistivity.

25

If the resistivity is increased too much the voltage on the second conductive layer  
 18 mid-way between the earthed points (that is, inside the stator) will be so high  
 that there will be risk of glow discharge and consequently erosion of the  
 conductive and the insulation.

30

The resistivity  $\rho_s$  of the second conductive layer 18 should therefore lie within an  
 interval:

$$\rho_{\min} < \rho_s < \rho_{\max} \quad (2)$$

where  $\rho_{\min}$  is determined by permissible power loss caused by eddy current losses  
 35 and resistive losses caused by  $U_{\text{ind}}$ .  $\rho_{\max}$  is determined by the requirement for no  
 glow discharge.

Experiments have shown that the resistivity  $\rho_s$  of the second conductive layer 18 should be between 10-500 ohm\*cm. To obtain good results with machines of all sizes  $\rho_s$  should be between 50-100 ohm\*cm.

- 5 Figure 3 shows a diagram illustrating potentials on the conductive surface in relation to the distance between earthing points.

10 An example of a suitable conductive layer 18 is one manufactured of EPDM material mixed with carbon black. The resistivity can be determined by varying the type of base polymer and/or varying the type of carbon black and/or the proportion of carbon black.

The following are a number of examples of different resistivity values obtained using various mixtures of base polymer and carbon black.

15

Base polymer	Carbon black type	Carbon black quantity %	Volume resistivity ohm*cm
Ethylene vinyl acetate copolymer/nitrile rubber	EC carbon black	approx. 15	350 - 400
""	P-carbon black	approx. 37	70 - 10
""	Extra conducting carbon black, type I	approx. 35	40 - 50
""	Extra conducting carbon black, type II	approx. 33	30 - 60
Butyl grafted polythene	""	approx. 25	7 - 10
Ethylene butyl acrylate copolymer	Acetylene carbon black	approx. 35	40 - 50

""	P carbon black	approx. 38	5 - 10
Ethylene propene rubber	Extra conducting carbon black	approx. 35	200 - 400

The invention is not limited to the embodiments shown. Several variations are feasible within the scope of the appended claims.

## CLAIMS

1. An insulated conductor (10) for high-voltage windings in electric machines, characterized in that the insulated conductor (10) comprises one or more strands (12), an inner, first conductive layer (14) surrounding the strands (12), a first insulating layer (16) surrounding the inner, first conductive layer (14) and an outer, second conductive layer (18) surrounding the first insulating layer (16).
2. An insulated conductor (10) as claimed in claim 1, characterized in that the conductive layer (18) is earthed at at least two different points along the insulated conductor (10).
3. An insulated conductor (10) as claimed in claim 2, characterized in that the resistivity of the second conductive layer (18) is lower than that of the insulation layer (16) but higher than that of the material of the strands (12).
4. An insulated conductor (10) as claimed in claim 3, characterized in that the resistivity of the second conductive layer (18) is between 0.1-1000 ohm\*cm.
5. An insulated conductor (10) as claimed in claim 4, characterized in that the resistivity of the second conductive layer (18) is between 10-500 ohm\*cm.
6. An insulated conductor (10) as claimed in claim 5, characterized in that the resistivity of the second conductive layer (18) is between 50-100 ohm\*cm.
7. An insulated conductor (10) as claimed in claim 1, characterized in that the resistance per axial length unit of the second conductive layer (18) is between 5-50000 ohm/m.

8. An insulated conductor (10) as claimed in claim 1, characterized in that the resistance per axial length unit of the second conductive layer (18) is between 500-25000 ohm/m.
- 5 9. An insulated conductor (10) as claimed in claim 1, characterized in that the resistance per axial length unit of the second conductive layer (18) is between 2500-5000 ohm/m.
- 10 10. An insulated conductor (10) as claimed in any of the preceding claims, characterized in that the resistivity of the second conductive layer (18) is determined by varying the type of base polymer and varying the type of carbon black and the proportion of carbon black.
- 15 11. An insulated conductor (10) as claimed in claim 9, characterized in that the base polymer is chosen from ethylene butyl acrylate copolymers of EP-rubber.
- 20 12. An insulated conductor (10) as claimed in claims 9-10, characterized in that the second conductive layer (18) is cross-linked by peroxide.
- 25 13. An insulated conductor (10) as claimed in any of the preceding claims, characterized in that the adhesion between the insulation layer (16) and the second conductive layer (18) is of the same order of magnitude as the intrinsic strength of the insulation material.
- 30 14. An insulated conductor (10) as claimed in any of the preceding claims, characterized in that the first conductive layer (14), the insulating layer (16) and the second conductive layer (18) are extruded on the conductive strands (12).
- 35 15. An insulated conductor (10) as claimed in claim 13, characterized in that all layers are applied through extrusion through a multi layer head.

16. An insulated conductor (10) as claimed in any of the preceding claims, characterized in that the insulating layer (16) is a crosslinked polyethylene, XLPE.

5 17. An insulated conductor (10) as claimed in any of the preceding claims, characterized in that the insulating layer (16) is made of ethylenepropylene rubber or silicone rubber..

10 18. An insulated conductor (10) as claimed in any of the preceding claims characterized in that the insulating layer (16) is made of a thermoplastic material as LDPE, HDPE, PP, PB, PMP.

19. An electric machine comprising an insulated conductor as claimed in any of claims 1-18.

15

20. An rotating electrical machine comprising an insulated conductor as claimed in any of claims 1-18.

20

1 / 2

Fig. 1

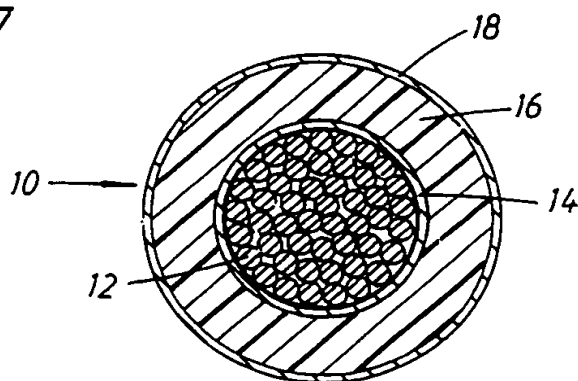


Fig. 3

Calculated potential on the conductive surface at AC-voltage  
84 kV(rms)

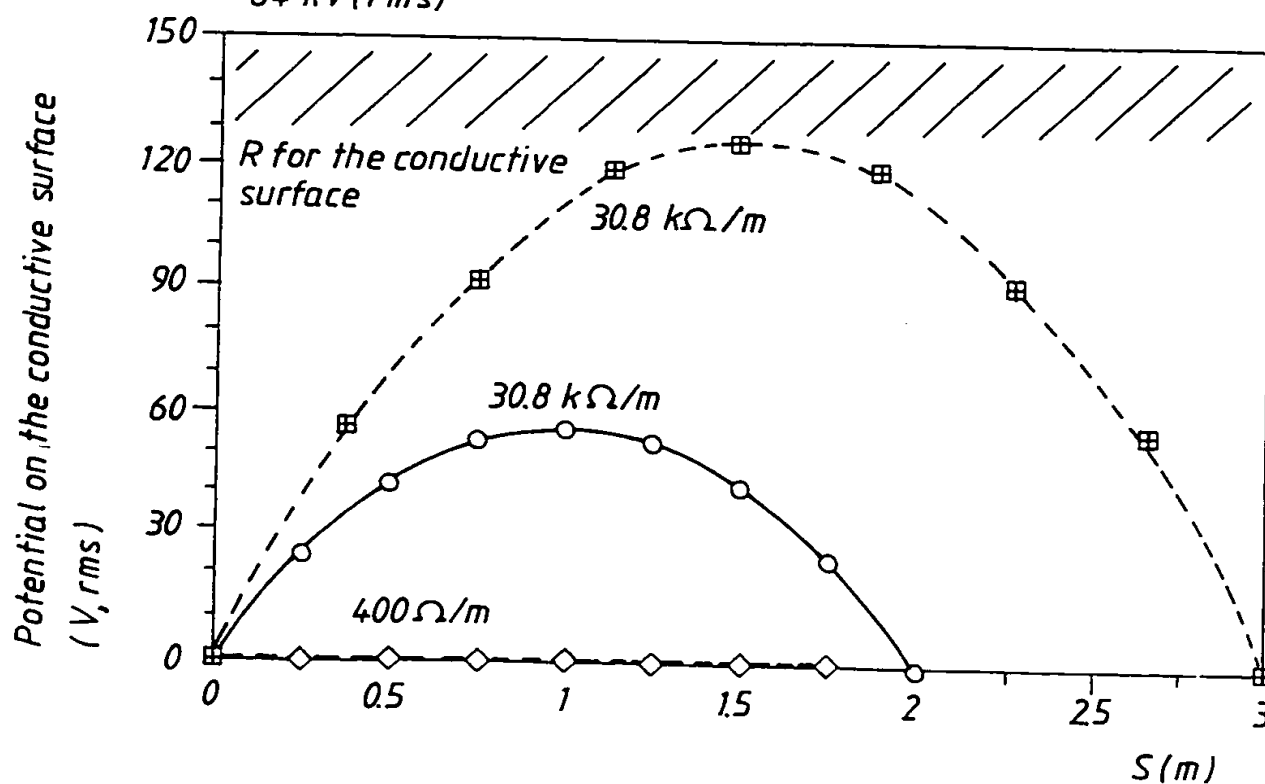
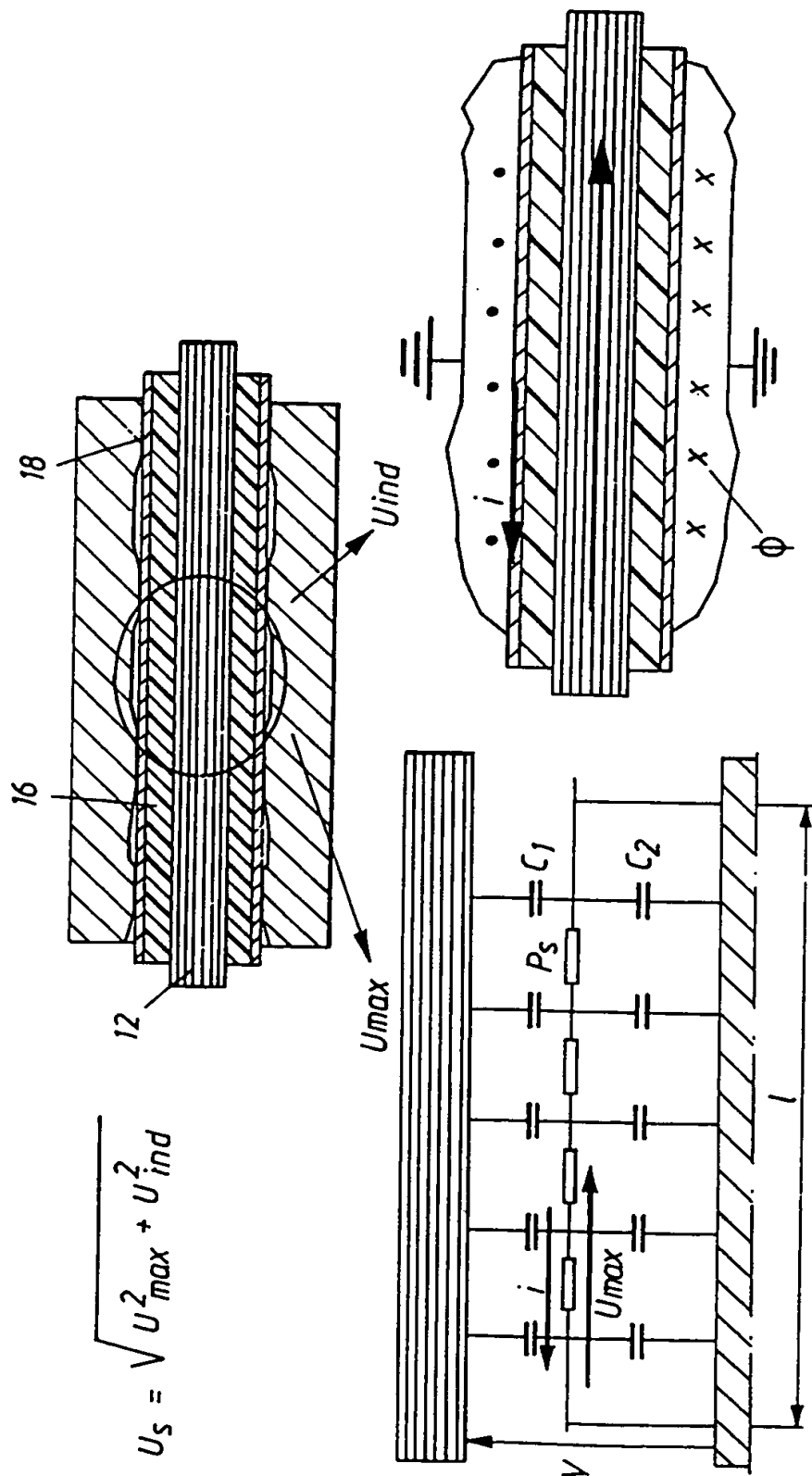


Fig. 2





## INTERNATIONAL SEARCH REPORT

International application No.

PCT/SE 97/00903

## A. CLASSIFICATION OF SUBJECT MATTER

IPC6: H02K 3/40, H02K 15/08, H01B 9/02  
According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC6: H01B, H02K

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

## WPI, CLAIMS

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 4109098 A (MATS GUNNAR OLSSON ET AL.), 22 August 1978 (22.08.78), column 2, line 50 - column 4, line 29, figure 1, abstract	1-4,7-15
Y	--	16-20
Y	US 4317001 A (DAVID A. SILVER ET AL.), 23 February 1982 (23.02.82), column 2, line 28 - column 3, line 36, figure 1, abstract	16-18
Y	US 3891880 A (HELMUT BRITSCH), 24 June 1975 (24.06.75), column 4, line 28 - line 57, figure 2, abstract	19-20
	--	

☒ Further documents are listed in the continuation of Box C.☒ See patent family annex.

- \* Special categories of cited documents:
- "A" document defining the general state of the art which is not considered to be of particular relevance
  - "E" earlier document but published on or after the international filing date
  - "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
  - "O" document referring to an oral disclosure, use, exhibition or other means
  - "P" document published prior to the international filing date but later than the priority date claimed
  - "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
  - "X" document of particular relevance: the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
  - "Y" document of particular relevance: the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
  - "&" document member of the same patent family

Date of the actual completion of the international search

2 Sept 1997

Date of mailing of the international search report

04 -09- 1997

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## INTERNATIONAL SEARCH REPORT

International application No.

PCT/SE 97/00903

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP 0049104 A1 (BICC LIMITED), 7 April 1982 (07.04.82), abstract  -- -----	1-21

**INTERNATIONAL SEARCH REPORT**  
Information on patent family members

06/08/97

International application No.  
PCT/SE 97/00903

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 4109098 A	22/08/78	AR 211382 A	15/12/77
		AU 7707175 A	08/07/76
		BE 825068 A	15/05/75
		BR 7500229 A	04/11/75
		CA 1038052 A	05/09/78
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		DE 2501811 A	14/08/75
		FR 2260173 A,B	29/08/75
		GB 1493163 A	23/11/77
		JP 50109479 A	28/08/75
		NL 7501168 A	04/08/75
		SE 384420 B,C	03/05/76
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US 4317001 A	23/02/82	AR 222689 A	15/06/81
		BR 8001105 A	29/10/80
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		SE 445789 B,C	14/07/86
		SE 8001418 A	24/08/80
		US 4384944 A	24/05/83
US 3891880 A	24/06/75	AT 328548 B	25/03/76
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		SE 395802 B,C	22/08/77
EP 0049104 A1	07/04/82	GB 2084385 A,B	07/04/82

## PCT

## INTERNATIONAL PRELIMINARY EXAMINATION REPORT

(PCT Article 36 and Rule 70)

Applicant's or agent's file reference P 97-248/FA/PA	FOR FURTHER ACTION See Notification of Transmittal of International Preliminary Examination Report (Form PCT/IPEA/416)	
International application No. PCT/SE97/00903	International filing date (day/month/year) 27.05.1997	Priority date (day/month/year) 29.05.1996
International Patent Classification (IPC) or national classification and IPC <sub>6</sub> H 02 K 3/40, 15/08; H 01 B 9/02		
Applicant Asea Brown Boveri AB et al.		

1. This international preliminary examination report has been prepared by this International Preliminary Examining Authority and is transmitted to the applicant according to Article 36.

2. This REPORT consists of a total of 4 sheets, including this cover sheet.

☒ This report is also accompanied by ANNEXES, i.e., sheets of the description, claims and/or drawings which have been amended and are the basis for this report and/or sheets containing rectifications made before this Authority (see Rule 70.16 and Section 607 of the Administrative Instructions under the PCT).

These annexes consist of a total of 2 sheets.

3. This report contains indications relating to the following items:

- I ☒ Basis of the report
- II ☐ Priority
- III ☐ Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
- IV ☐ Lack of unity of invention
- V ☒ Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement
- VI ☐ Certain documents cited
- VII ☐ Certain defects in the international application
- VIII ☐ Certain observations on the international application

Date of submission of the demand 22.12.1997	Date of completion of this report 01.10.1998
Name and mailing address of the IPEA/SE Patent- och registreringsverket Box 5055 S-102 42 STOCKHOLM Telex 17978 PATOREG-S	Authorized officer Karin Säfsten Telephone No. 08-700 25 00

## INTERNATIONAL PRELIMINARY EXAMINATION REPORT

International application No.

PCT/SE97/00903

## 1. Basis of the report

1. This report has been drawn on the basis of *(Replacement sheets which have been furnished to the receiving Office in response to an invitation under Article 14 are referred to in this report as "originally filed" and are not annexed to the report since they do not contain amendments.)*

☐ the international application as originally filed.

☒ the description, pages 1-14, as originally filed,  
pages \_\_\_\_\_, filed with the demand,  
pages \_\_\_\_\_, filed with the letter of \_\_\_\_\_,  
pages \_\_\_\_\_, filed with the letter of \_\_\_\_\_.

☒ the claims, Nos. \_\_\_\_\_, as originally filed,  
Nos. \_\_\_\_\_, as amended under Article 19,  
Nos. \_\_\_\_\_, filed with the demand,  
Nos. 1-18, filed with the letter of 24.09.1998,  
Nos. \_\_\_\_\_, filed with the letter of \_\_\_\_\_.

☒ the drawings, sheets/fig 1-3, as originally filed,  
sheets/fig \_\_\_\_\_, filed with the demand  
sheets/fig \_\_\_\_\_, filed with the letter of \_\_\_\_\_,  
sheets/fig \_\_\_\_\_, filed with the letter of \_\_\_\_\_.

## 2. The amendments have resulted in the cancellation of:

☐ the description, pages \_\_\_\_\_

☐ the claims, Nos. \_\_\_\_\_

☐ the drawings, sheets/fig \_\_\_\_\_

3. ☐ This report has been established as if (some of) the amendments had not been made, since they have been considered to go beyond the disclosure as filed, as indicated in the supplemental Box (Rule 70.2(c)).

## 4. Additional observations, if necessary:

## INTERNATIONAL PRELIMINARY EXAMINATION REPORT

International application No.

PCT/SE97/00903

## V. Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability, citations and explanations supporting such statement

## 1. Statement

Novelty (N)	Claims	<u>1-18</u>	YES
	Claims		NO
Inventive step (IS)	Claims	<u>1-18</u>	YES
	Claims		NO
Industrial applicability (IA)	Claims	<u>1-18</u>	YES
	Claims		NO

## 2. Citations and explanations

The present invention relates to an insulated conductor for high-voltage windings in electric machines, and to a rotating or static electric machine comprising such an insulated conductor, and the object is to provide such a conductor in which the insulation can withstand the high temperatures and high electric field strengths caused by the high voltage.

The invented solution consists of an insulated conductor comprising on or more strands, an inner, semi-conductive layer surrounding the strands, a first insulating layer, and an outer semi-conductive layer. Said outer semi-conductive layer has a resistivity that minimizes the electric losses and the risk of electrical discharges, i.e a resistivity between 10-500 ohm\*cm.

New claims 1-18 were filed on 1998-09-24, wherein new claim 1 is amended to comprise the features of previous claims 1 and 5, and previous claim 4 is deleted.

The following documents are included in the International Search Report:

D1: US 4109098 A (MATS GUNNAR OLSSON ET AL.), 22 August 1978

D2: US 4317001 A (DAVID A. SILVER ET AL.), 23 February 1982, shows insulation of an electric power cable.

D3: US 3891880 A (HELMUT BRITSCH), 24 June 1975, shows protection of a high voltage winding against glow discharge by application of a wound-on tape of semi-conductive material.

D4: EP 0049104 A1 (BICC LIMITED), 7 April 1982, shows electric cables with a semiconducting screening layer.

.../...

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

International application No.

PCT/SE97/00903

Supplemental Box

(To be used when the space in any of the preceding boxes is not sufficient)

Continuation of: Box V.

The closest prior art is found in D1:

D1 (see column 2, line 50-column 4, line 29; figure 1; abstract) shows a high voltage cable, with a core which may consist of twisted wires, an inner layer of semi-conducting material surrounding the core, an insulation layer, and an outer semiconducting layer, having a surface resistivity within the range of  $10^7$  and  $10^9$  ohm/square, with a grounded metallic screen applied thereon.

The subject matter claimed in amended claim 1 differs from what is known from D1 in the sense that the conductor is intended for windings in electric machines, and in the sense that the resistivity of the second conductive layer is between 10-500 ohm\*cm. This is not obvious to one skilled in the art, since the high-voltage cable according to D1 is not designed for use in windings in electric machines, and the selection of the volume resistivity is not discussed at all. The invention claimed in amended claim 1 is therefore considered to involve an inventive step.

Consequently, the invention claimed in claims 1-18 is considered to be novel(N), to involve an inventive step(IS), and to comprise industrial applicability(IA).

24 -09- 1998

CLAIMS

1. An insulated conductor (10) for high-voltage windings in electric machines, characterized in that the insulated conductor (10) comprises one or more  
5 strands (12), an inner, first conductive layer (14) surrounding the strands (12), a first insulating layer (16) surrounding the inner, first conductive layer (14) and an outer, second conductive layer (18) surrounding the first insulating layer (16), and the resistivity of the second conductive layer (18) is between 10-500 ohm\*cm.
- 10 2. An insulated conductor (10) as claimed in claim 1, characterized in that the conductive layer (18) is earthed at at least two different points along the insulated conductor (10).
3. An insulated conductor (10) as claimed in claim 2, characterized in  
15 that the resistivity of the second conductive layer (18) is lower than that of the insulation layer (16) but higher than that of the material of the strands (12).
4. An insulated conductor (10) as claimed in claim 3, characterized in  
20 that the resistivity of the second conductive layer (18) is between 50-100 ohm\*cm.
5. An insulated conductor (10) as claimed in claim 1, characterized in  
that the resistance per axial length unit of the second conductive layer (18) is between 5-50000 ohm/m.
- 25 6. An insulated conductor (10) as claimed in claim 1, characterized in  
that the resistance per axial length unit of the second conductive layer (18) is between 500-25000 ohm/m.
7. An insulated conductor (10) as claimed in claim 1, characterized in  
30 that the resistance per axial length unit of the second conductive layer (18) is between 2500-5000 ohm/m.
8. An insulated conductor (10) as claimed in any of the preceding claims,  
characterized in that the resistivity of the second conductive layer (18) is  
35 determined by varying the type of base polymer and varying the type of carbon black and the proportion of carbon black.



9. An insulated conductor (10) as claimed in claim 7, characterized in that the base polymer is chosen from ethylene butyl acrylate copolymers of EP-rubber.
10. An insulated conductor (10) as claimed in claims 7-8, characterized in that the second conductive layer (18) is cross-linked by peroxide.
11. An insulated conductor (10) as claimed in any of the preceding claims, characterized in that the adhesion between the insulation layer (16) and the second conductive layer (18) is of the same order of magnitude as the intrinsic strength of the insulation material.
12. An insulated conductor (10) as claimed in any of the preceding claims, characterized in that the first conductive layer (14), the insulating layer (16) and the second conductive layer (18) are extruded on the conductive strands (12).
13. An insulated conductor (10) as claimed in claim 11, characterized in that all layers are applied through extrusion through a multi layer head.
14. An insulated conductor (10) as claimed in any of the preceding claims, characterized in that the insulating layer (16) is a crosslinked polyethylene, XLPE.
15. An insulated conductor (10) as claimed in any of the preceding claims, characterized in that the insulating layer (16) is made of ethylenepropylene rubber or silicone rubber.
16. An insulated conductor (10) as claimed in any of the preceding claims characterized in that the insulating layer (16) is made of a thermoplastic material as LDPE, HDPE, PP, PB, PMP.
17. An electric machine comprising an insulated conductor as claimed in any of claims 1-16.
18. An rotating electrical machine comprising an insulated conductor as claimed in any of claims 1-16.

## INTERNATIONAL SEARCH REPORT

International application No.

PCT/SE 97/00903

## A. CLASSIFICATION OF SUBJECT MATTER

IPC6: H02K 3/40, H02K 15/08, H01B 9/02

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC6: H01B, H02K

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

## WPI, CLAIMS

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 4109098 A (MATS GUNNAR OLSSON ET AL.), 22 August 1978 (22.08.78), column 2, line 50 - column 4, line 29, figure 1, abstract	1-4, 7-15
Y	--	16-20
Y	US 4317001 A (DAVID A. SILVER ET AL.), 23 February 1982 (23.02.82), column 2, line 28 - column 3, line 36, figure 1, abstract	16-18
Y	US 3891880 A (HELMUT BRITSCH), 24 June 1975 (24.06.75), column 4, line 28 - line 57, figure 2, abstract	19-20
	--	

☒ Further documents are listed in the continuation of Box C.☒ See patent family annex.

\* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or prior date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance: the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance: the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&amp;" document member of the same patent family

Date of the actual completion of the international search

2 Sept 1997

Date of mailing of the international search report

04-09-1997

Name and mailing address of the ISA/

Authorized officer

## INTERNATIONAL SEARCH REPORT

International application No.

PCT/SE 97/00903

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP 0049104 A1 (BICC LIMITED), 7 April 1982 (07.04.82), abstract  -----	1-21

INTERNATIONAL SEARCH REPORT  
Information on patent family members

06/08/97

International application No.  
PCT/SE 97/00903

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 4109098 A	22/08/78	AR 211382 A	15/12/77
		AU 7707175 A	08/07/76
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